

## CLAIMS

- 1 1. A method for controlling the temperature of a mass cooled by a free piston cryocooler,  
2 the method comprising:
  - 3 (a) for output cooling power demands requiring a piston stroke exceeding a selected  
4 minimum piston stroke, controlling the output cooling power of the cryocooler by  
5 modulating piston stroke as an increasing function of the difference between  
6 sensed mass temperature and a command reference input temperature; and
  - 7 (b) for output cooling power demands requiring a piston stroke less than the selected  
8 minimum piston stroke, maintaining the minimum piston stroke and applying  
9 thermal energy to the mass.
- 1 2. A method in accordance with claim 1, wherein the selected minimum piston stroke is  
2 the minimum piston stroke necessary to maintain gas bearing lubrication of the  
3 cryocooler.
- 1 3. A method in accordance with claim 2, wherein, for output cooling power demands  
2 requiring a piston stroke less than the selected minimum piston stroke, the thermal energy  
3 is applied as an increasing function of the difference between the cooling power applied  
4 to the mass by the cryocooler at the selected minimum piston stroke and the cooling  
5 power demand.

1 4. A method in accordance with claim 3, wherein, for nominal design operation, the  
2 output cooling power demand is greater than the output cooling power at the selected  
3 minimum piston stroke and is nearer the output cooling power at the selected minimum  
4 piston stroke than it is to the cooling power at a maximum permissible piston stroke.

1 5. A method for controlling the temperature of a mass cooled by a free piston cryocooler,  
2 the cryocooler having a piston and a closed loop control system, the control system  
3 deriving a piston drive signal from the difference between a set point signal and a fed  
4 back temperature signal representing the temperature of the mass, the method  
5 comprising:

- 6 (a) for piston drive signals corresponding to piston strokes exceeding a selected  
7 minimum piston stroke, controlling the output cooling power of the cryocooler by  
8 the piston drive signal;
- 9 (b) for piston drive signals corresponding to piston strokes less than the minimum  
10 piston stroke, maintaining the minimum piston stroke; and
- 11 (c) for piston drive signals corresponding to piston strokes less than the minimum  
12 piston stroke, applying thermal energy to the mass as an increasing function of the  
13 difference between the piston drive signal for the minimum piston stroke and the  
14 applied piston drive signal.

1 6. A method in accordance with claim 5, wherein the selected minimum piston stroke is  
2 at the piston stroke necessary to maintain gas bearing lubrication of the cryocooler.

1 7. An improved, temperature controlled, free piston cryocooler including a free piston  
2 driven in reciprocation by a prime mover having a modulatable stroke, the cryocooler  
3 including a cold end and a warm end and being capable of transporting heat away from a  
4 thermal load positioned at the cold end, the cryocooler having a feedback control system  
5 including (i) a temperature command input for inputting a reference signal representing a  
6 desired cold end temperature of the thermal load, (ii) a feedback loop including a  
7 temperature sensor at the cold end for generating a signal representing actual cold end  
8 temperature, and (iii) a summing junction for generating an actuating signal representing  
9 the difference between the desired temperature and the actual temperature of the cold  
10 end, the improvement comprising the combination of:

11 (a) a piston stroke modulator connected to receive the actuating signal and for  
12 converting the actuating signal to a piston drive signal representing a desired  
13 piston stroke, the modulator connected to the prime mover for controlling its  
14 stroke when the desired piston stroke exceeds a selected minimum stroke and  
15 maintaining the minimum stroke when the desired stroke is less than the  
16 minimum stroke; and

17 (b) a heating apparatus including a heater in thermal connection to the cold end and a  
18 heater control element having an input connected to receive the piston drive signal

19           for modulating the heater power as an increasing function of the difference  
20           between the desired piston stroke and the minimum piston stroke when the  
21           desired piston stroke is less than the minimum piston stroke.

1    8. An improved closed loop control system for controlling a free piston cryocooler having  
2    a heat pump including a piston, the control system controlling the temperature of a mass  
3    being cooled by the cryocooler and including (i) a dynamic leg, (ii) a reference input for  
4    inputting a desired, set point temperature and (iii) a feedback leg including a temperature  
5    sensor in thermally conductive connection to the mass being cooled, for comparison of a  
6    signal from the temperature sensor to the reference input to provide an actuating signal,  
7    the improvement comprising:

8           (a) a first branch of the dynamic leg comprising:

9               (i) a first controlled element including the prime mover and the heat pump  
10              and controlling the piston amplitude of oscillation; and  
11              (ii) a first control element having an output connected to an input of the  
12              first controlled element and an input to which the actuating signal is  
13              applied for controlling the piston amplitude of oscillation, the first control  
14              element including an actuating signal limiter for maintaining the output of  
15              the first control element greater than a selected piston limit value  
16              substantially corresponding to a minimum piston stroke; and

17           (b) a second, parallel branch of the dynamic leg comprising:

18 (i) a second controlled element including a heater in thermally conductive  
19 connection to the mass; and  
20 (ii) a second control element having an output connected to an input of the  
21 second controlled element and an input to which an actuating signal is  
22 applied for controlling the heating power output of the heater, the second  
23 control element, for an actuating signal value exceeding the selected  
24 piston limit value, applying substantially no heating power and, for an  
25 actuating signal value less than the selected piston limit value, applying  
26 increasing heating power as a function of decreasing actuating signal  
27 value.

1 9. A control system in accordance with claim 8 wherein the control elements comprise a  
2 digital microprocessor and associated storage forming a programmed computer system  
3 having control instructions and algorithms stored in the storage.